[RADIOCARBON, VOL. 40, NO. 3, 1998, P. 1117–1125]

REVISION AND TENTATIVE EXTENSION OF THE TREE-RING BASED ^{14}C CALIBRATION, 9200–11,855 CAL BP

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ABSTRACT. We report radiocarbon calibration data based on the revised German oak and pine series. The age range of the absolutely dated German oak series has been extended to 10,430 cal BP. The German pine series is tentatively linked to the oak series by ^{14}C, and now reaches back to 11,871 cal BP (±20 yr). The revisions of the tree-ring time scale of the German oak chronology solved long-standing apparent discrepancies in the mid-Holocene ^{14}C calibration data sets. The calibration data set based on the floating German pine is now in close agreement with the Preboreal part of ^{14}C calibration series obtained from most varve chronologies and corals.

INTRODUCTION

We previously published ^{14}C calibration data sets based on the German oak and pine series (Kromer and Becker 1993) reaching back to 11,500 cal BP. At that time the absolute time scale of the German pine chronology was based on a tentative tree-ring synchronization to the German oak master (Becker 1993). Since then, the tree-ring scale of both the German oak and the link to the pine has had to be revised (Spurk *et al.* 1998). We present the revised data sets for both series (Tables 1 and 2, following References) and discuss their implications for the atmospheric ^{14}C level at the transition from the Younger Dryas to the Preboreal and into the Boreal. Both chronologies were extended by findings made since 1993. For these intervals additional ^{14}C calibration dates are reported here.

^{14}C-DATED TREE-RING SERIES

German Oak

The tree-ring scale of the German oak chronology (Becker 1993) had to be revised at two intervals: at 7190 cal BP and 9740 cal BP (Spurk *et al.* 1998) rings were missing in the chronology. The corrections lead to shifts of 41 and 54 yr, respectively, to older ages. The error at 7190 cal BP has been noted already in the comparison of ^{14}C data sets (Stuiver and Pearson 1993; McCormac, Baillie and Pilcher 1995). Its correction also solved another apparent discrepancy: in 1986 the German oak in the 6th to the 8th millennia was floating but was wiggle-matched to the bristlecone pine (Linick, Suess and Becker 1985; Kromer *et al.* 1986; Stuiver *et al.* 1986), resulting in a zero-point range of 7190–7230 BC. When it was later synchronized dendrochronologically to the younger absolute oak chronology, the zero point became 7177 BC, raising suspicion of a true offset in the ^{14}C ages between the bristlecone pine and the German oak. After application of the 41-yr correction at 7150 cal BP, the two data sets are now fully compatible. The correction at 9740 cal BP solved an apparent offset in the German oak sections measured in Belfast (Pearson, Becker and Qua 1993) from those measured in Heidelberg (F. G. McCormac, personal communication).

Through new findings and synchronization of previously floating sections, the German oak chronology was extended by more than four centuries and now reaches back to 10,430 cal BP (Spurk *et al.*

absolute age scale is estimated at less than ±20 yr (see text).

1998). The ^{14}C calibration curve (Fig. 1) shows a pronounced and rapid transition from ^{14}C ages of 9200 BP to 8900 BP around 10,200 cal BP, which is now part of the oak chronology. This "marker" is used to constrain the absolute age of the floating German pine chronology with respect to the absolutely dated oak chronology.

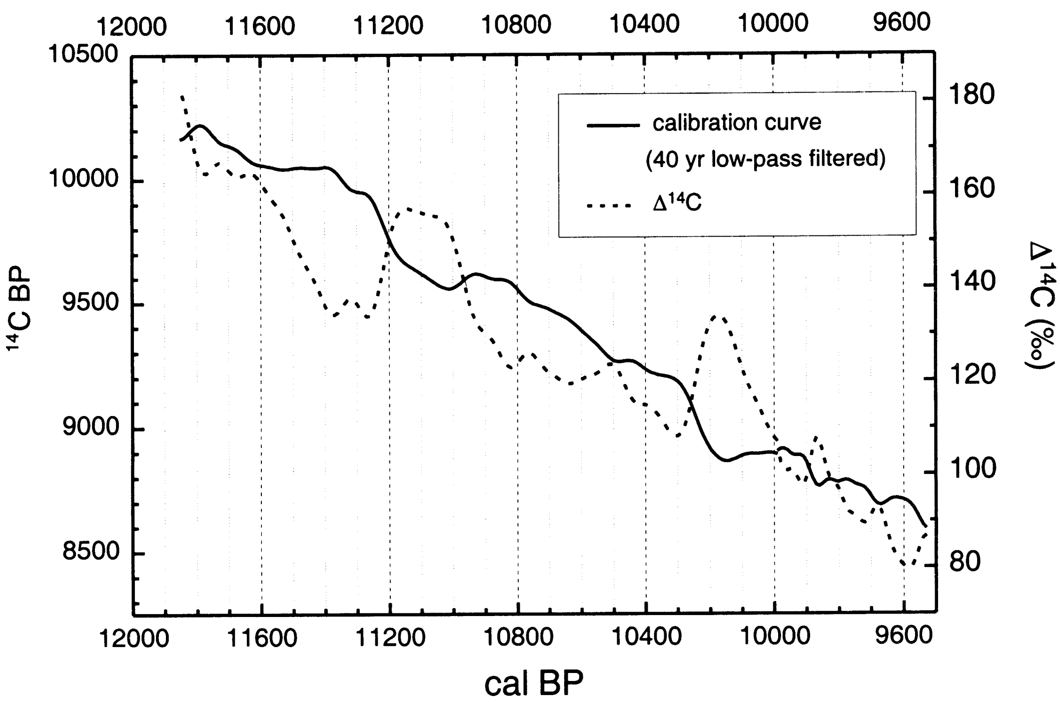

Fig. 3. Smoothed ^{14}C calibration curve (FFT filter, 40-yr low pass) and $\Delta^{14}C$ (---) (Stuiver and Pollach 1977) as derived from the German oak and pine series.

Obvious candidates for causes of the variable ^{14}C level are changes in ocean ventilation and ^{14}C production changes, *e.g.*, by solar activity variability (Stuiver and Braziunas 1993). The improved absolute age control and the high resolution of tree-ring based $\Delta^{14}C$ reconstruction will now allow a better discrimination among forcing and response mechanisms as seen in the atmospheric $\Delta^{14}C$.

^{14}C PATTERNS IN THE LATE YOUNGER DRYAS

We obtained ^{14}C data from two floating sections predating the German pine series. 1) At d'Olon, east of the Lake of Geneva, Switzerland, a 340-ring *Larix* section was found and submitted by J. P. Hurni, Moudon. The ^{14}C sequence (Fig. 4, Table 3)—overlapping in ^{14}C age with the German pine for the youngest rings—documents a straight relation between ^{14}C age and true years. 2) From the lignite area close to Cottbus, East Germany, we obtained a large quantity of pine sections. The ^{14}C

TABLE 3. ^{14}C ages of the floating VOD 505 chronology (Rhone River, Geneva, Switzerland)

Lab code (Hd-)	Center ring	^{14}C BP	Lab code (Hd-)	Center ring	^{14}C BP
16184	15	10309 ± 47	17325	150	10259 ± 28
16185	35	10342 ± 60	16779	230	10179 ± 21
16847	50	10335 ± 28	16812	270	10159 ± 24
16825	70	10281 ± 29	16866	328	10088 ± 37
16641	90	10290 ± 27	16824	330	10118 ± 24
16823	110	10218 ± 25			

https://doi.org/10.1017/S0033822200019160 Published online by Cambridge University Press

we allow for additional error components, *e.g.*, arising from wood splitting or unequal spacing of the pine samples (most notable in the interval 10,200 to 10,230 cal BP), the German pine chronology is now fixed absolutely to the oak with an uncertainty better than ±20 yr. All ^{14}C pine data as reported below are based on this match.

Calibration Curve and Atmospheric ^{14}C Levels in the Age Range 9400 to 11,855 cal BP

The calibration curve based on the German pine is shown in Figure 2. Strong departures from a steady-state ^{14}C level are noted. A smoothed version of Figure 2 (FFT-smoothing with a 40-yr cut-off) and the $\Delta^{14}C$ level as calculated from the smoothed data are shown in Figure 3.

Superimposed on a continuously declining long-term trend are century-scale peaks of ^{14}C rising by up to 30‰ above the long-term mean. Following the end of the Younger Dryas (11,650–11,550 cal BP) we observe a decline of $\Delta^{14}C$, followed by a strong century-scale peak in the early Preboreal. This oscillation is synchronous to the evidence of Preboreal cooling documented in the stable isotope data of the Greenland ice cores and in mid-latitude archives, as discussed in detail elsewhere (Björck *et al.* 1996). The transition from the Preboreal to the Boreal chronozone, roughly coincident with the suppression of pine by oak in the river valleys of Southern Germany, is marked by another strong $\Delta^{14}C$ anomaly.

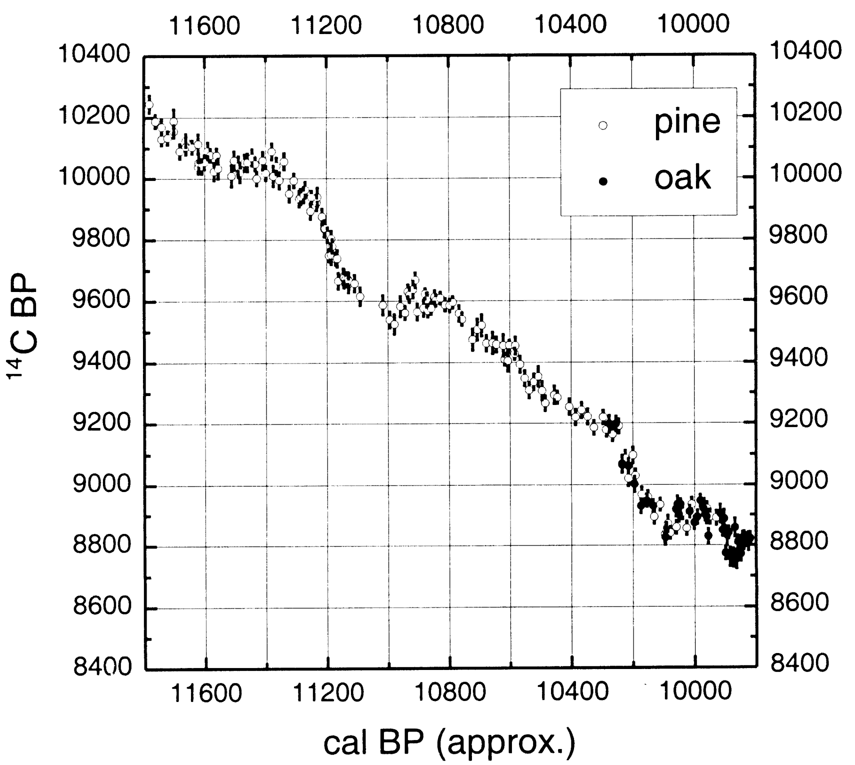

Fig. 2. ^{14}C calibration curve as derived from the German pine chronology. The uncertainty of the absolute age scale is estimated at less than ±20 yr (see text).

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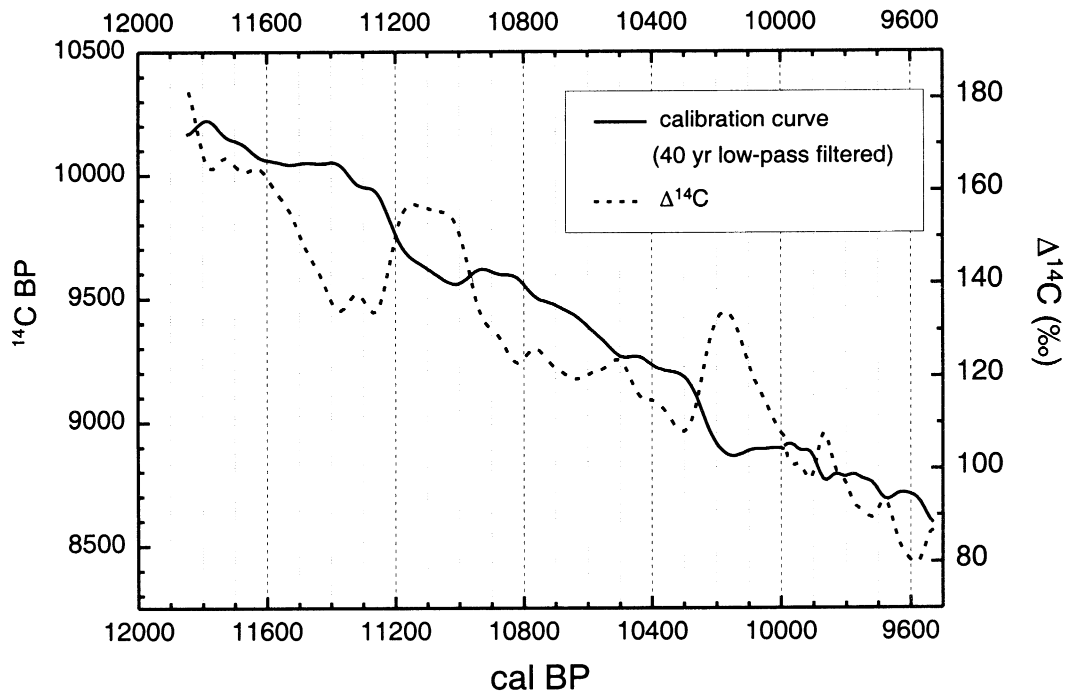

Fig. 3. Smoothed ^{14}C calibration curve (FFT filter, 40-yr low pass) and Δ^{14}C (---) (Stuiver and Pollach 1977) as derived from the German oak and pine series.

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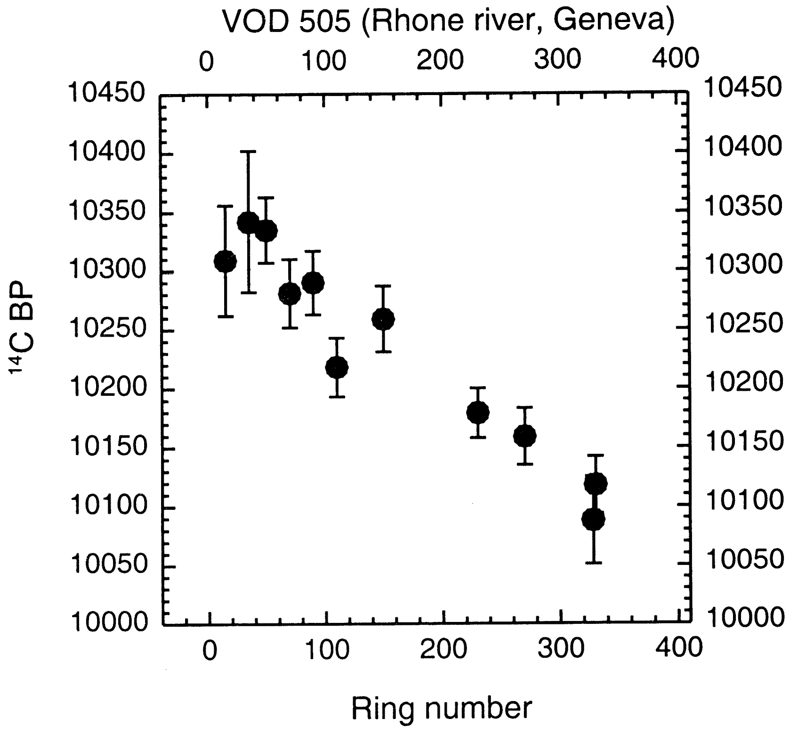

Fig. 4. ^{14}C dates *vs.* ring number of the floating *Larix* series VOD505 (Rhone River, Geneva, Switzerland). The sequence indicates an essentially "regular" age relation for this interval at the end of the Younger Dryas event.

ages of the samples analyzed so far cover the range 10,480 to 10,280 BP. From 7 sections we built a 296-ring chronology which is now being ^{14}C-dated. The oldest rings date to 10,280 ± 26 ^{14}C BP, raising hopes for a slight extension of the German pine chronology.

Conclusion

The revisions of the tree-ring time scale of the German oak chronology solved long-standing apparent discrepancies noted over the course of high-precision ^{14}C measurements. The extension of the German oak by more than 450 yr allows for a much improved ^{14}C link to the German pine chronology, constraining its absolute position with an error of less than ±20 yr. The calibration data set based on the German pine is now in close agreement with the Preboreal part of ^{14}C calibration series obtained from most varve chronologies and corals.

Acknowledgments

The main body of the German oak and pine chronologies was constructed by the late Bernd Becker. For the new extension of the chronologies we profited much from the work of Michael Friedrich, Jutta Hofmann and Sabine Remmele.

We thank Minze Stuiver and Paula Reimer for discussion and exchange during the course of ^{14}C analyses of the tree-ring series. Edouard Bard and Tomasz Goslar made us aware of the problems of the earlier oak-pine link. Svante Björck and Sigfus Johnson opened new vistas when the work on the tree-ring series seemed at a dead end.

The Cottbus pine sections were found and submitted by D. Neubauer-Saurer, Y. Gautier and C. Pasda. The *Larix* section was provided by J. P. Hurni, A. Orcel and C. Orcel, Laboratoire Romand de Dendrochronologie, Moudon, Switzerland.

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TABLE 1. Revised German oak data. Compared to the previous publication (Kromer and Becker 1993) data were added at the beginning of the chronology, and shifts of the dendroscale are included (see text).

Lab code (Hd-)	cal BC	cal BP	^{14}C BP
19079	8329	10278	9198 ± 27
19055	8307	10256	9199 ± 24
19054	8287	10236	9069 ± 27
19091	8267	10216	9062 ± 23
19175	8247	10196	9002 ± 25
19174	8227	10176	8930 ± 23
19179	8207	10156	8947 ± 20
19349	8187	10136	8930 ± 20
19415	8147	10096	8826 ± 24
15145	8113	10062	8918 ± 23
14904	8108	10057	8934 ± 28
19350	8107	10056	8923 ± 20
15889	8103	10052	8901 ± 23
15923	8098	10047	8935 ± 18
16046	8068	10017	8911 ± 20
15906	8053	10002	8874 ± 20
16632	8043	9992	8893 ± 23
16038	8033	9982	8947 ± 20
16587	8023	9972	8921 ± 20
16586	8018	9967	8901 ± 20
16585	8013	9962	8894 ± 23
19351	8007	9956	8830 ± 24
9513	7968	9917	8904 ± 30
14075	7961	9910	8850 ± 20
9502	7956	9905	8887 ± 30
14076	7951	9900	8774 ± 20
9501	7946	9895	8832 ± 30
14077	7941	9890	8842 ± 20
9492	7936	9885	8762 ± 30
14079	7931	9880	8764 ± 20
9491	7926	9875	8760 ± 30
14112	7921	9870	8858 ± 30
9486	7916	9865	8755 ± 30
16623	7911	9860	8810 ± 22
14274	7901	9850	8772 ± 23
16605	7896	9845	8823 ± 21
9264	8051	9840	8816 ± 30
14088	8046	9835	8818 ± 21
9258	7876	9825	8813 ± 30
14106	7871	9820	8822 ± 21
14171	7851	9800	8820 ± 23
9255	7836	9785	8801 ± 30
14160	7831	9780	8791 ± 24
14172	7821	9770	8772 ± 21
8510	7717	9666	8721 ± 30
8511	7709	9658	8721 ± 30
8518	7701	9650	8648 ± 30
8519	7694	9643	8710 ± 30
8524	7679	9628	8733 ± 30
8525	7669	9618	8708 ± 30
8544	7659	9608	8735 ± 30
8141	7653	9602	8719 ± 30
8140	7637	9586	8727 ± 33
8091	7620	9569	8739 ± 30
8144	7613	9562	8696 ± 30
8286	7613	9562	8736 ± 30
8145	7603	9552	8746 ± 30
8295	7594	9543	8577 ± 30
8127	7588	9537	8528 ± 30
8244	7581	9530	8608 ± 30
8151	7578	9527	8474 ± 30
7758	7570	9519	8439 ± 30
8171	7558	9507	8509 ± 30
7759	7541	9490	8455 ± 30
8273	7523	9472	8458 ± 30
8304	7473	9422	8371 ± 30
7760	7460	9409	8279 ± 30
8086	7423	9372	8315 ± 30
7757	7421	9370	8300 ± 30
8306	7408	9357	8382 ± 30
8117	7390	9339	8380 ± 30
8689	7268	9217	8296 ± 30
8717	7261	9210	8251 ± 30
8718	7251	9200	8198 ± 30
8719	7241	9190	8239 ± 30
8720	7231	9180	8232 ± 30
8750	7221	9170	8277 ± 30
8751	7210	9159	8271 ± 30

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TABLE 2. Revised German pine data. The absolute ages are tentative. They are based on matching the ^{14}C ages of the pine to the German oak. The uncertainty of the absolute age scale is estimated to be less than ±20 yr (see text).

Lab code (Hd-)	cal BC	cal BP	^{14}C BP
16342	9908	11857	10162 ± 23
16427	9878	11827	10156 ± 29
16251	9833	11782	10244 ± 28
17017	9813	11762	10188 ± 21
15586	9793	11742	10170 ± 24
16269	9793	11742	10130 ± 20
15591	9773	11722	10134 ± 22
15592	9753	11702	10156 ± 20
16328	9753	11702	10189 ± 38
15594	9733	11682	10090 ± 24
15731	9713	11662	10126 ± 21
16332	9713	11662	10105 ± 26
15730	9693	11642	10104 ± 22
16022	9673	11622	10114 ± 32
16502	9673	11622	10038 ± 21
13511	9671	11620	10052 ± 32
13512	9661	11610	10040 ± 24
16902	9653	11602	10054 ± 23
13525	9641	11590	10091 ± 28
16667	9633	11582	10077 ± 21
13526	9621	11570	10023 ± 28
16652	9613	11562	10076 ± 23
10567	9607	11556	10033 ± 33
10568	9563	11512	10009 ± 35
12888	9555	11504	10059 ± 30
12945	9541	11490	10040 ± 33
12959	9536	11485	10020 ± 32
12960	9521	11470	10052 ± 27
12964	9511	11460	10053 ± 29
12965	9496	11445	10069 ± 27
14220	9486	11435	10048 ± 21
14185	9481	11430	10000 ± 22
14159	9461	11410	10059 ± 29
12999	9451	11400	10018 ± 23
13000	9431	11380	10089 ± 27
12967	9426	11375	10008 ± 33
12968	9416	11365	10041 ± 27
12981	9406	11355	9994 ± 26
12982	9391	11340	10056 ± 27
9097	9374	11323	9950 ± 26
9098	9359	11308	9993 ± 22
9118	9342	11291	9934 ± 26
11647	9337	11286	9941 ± 25
11648	9327	11276	9947 ± 25
9119	9322	11271	9963 ± 26
11653	9304	11253	9893 ± 25
9126	9302	11251	9939 ± 20
11670	9284	11233	9921 ± 25
9127	9282	11231	9939 ± 30
11671	9267	11216	9875 ± 25
9134	9259	11208	9837 ± 26
11685	9257	11206	9838 ± 25
9810	9249	11198	9816 ± 23
9969	9244	11193	9749 ± 20
9135	9237	11186	9751 ± 31
11686	9237	11186	9804 ± 25
9811	9233	11182	9780 ± 22
9970	9222	11171	9738 ± 20
9153	9217	11166	9739 ± 27
9807	9214	11163	9665 ± 26
9808	9197	11146	9680 ± 26
13009	9195	11144	9673 ± 30
11715	9194	11143	9677 ± 18
9836	9190	11139	9670 ± 22
11729	9182	11131	9671 ± 23
13010	9180	11129	9656 ± 28
9837	9179	11128	9665 ± 26
13059	9160	11109	9657 ± 27
13087	9142	11091	9615 ± 29
13088	9067	11016	9586 ± 31
13094	9045	10994	9539 ± 26
13016	9030	10979	9524 ± 32
13017	9010	10959	9582 ± 33
13018	8995	10944	9561 ± 21
14231	8985	10934	9630 ± 22
13095	8980	10929	9619 ± 24
9844	8968	10917	9637 ± 27
14397	8961	10910	9668 ± 24
9853	8954	10903	9564 ± 26
9864	8934	10883	9576 ± 26
9005	8929	10878	9623 ± 16
8826	8924	10873	9603 ± 23
14375	8920	10869	9568 ± 20
8835	8909	10858	9576 ± 19
9865	8898	10847	9613 ± 20
8836	8894	10843	9601 ± 18
8867	8879	10828	9609 ± 19
8868	8864	10813	9587 ± 20
8876	8849	10798	9585 ± 20
8877	8839	10788	9595 ± 19
8889	8819	10768	9559 ± 25
8890	8809	10758	9540 ± 20
8911	8774	10723	9474 ± 34
8904	8759	10708	9506 ± 34
8905	8744	10693	9520 ± 34
8977	8729	10678	9462 ± 25
8957	8709	10658	9463 ± 34
8978	8696	10645	9458 ± 24
8970	8674	10623	9455 ± 34
9026	8669	10618	9410 ± 19

TABLE 2. *(Continued)*

Lab code (Hd-)	cal BC	cal BP	^{14}C BP
8971	8659	10608	9405 ± 34
9007	8654	10603	9456 ± 15
8989	8636	10585	9428 ± 18
9064	8634	10583	9454 ± 27
9154	8619	10568	9394 ± 26
9160	8604	10553	9348 ± 25
9161	8589	10538	9309 ± 25
9191	8574	10523	9336 ± 26
9192	8559	10508	9354 ± 32
9199	8546	10495	9307 ± 30
10001	8536	10485	9266 ± 24
10191	8506	10455	9293 ± 29
10003	8496	10445	9285 ± 20
10010	8457	10406	9254 ± 25
10011	8437	10386	9220 ± 25
10035	8417	10366	9243 ± 25
10036	8397	10346	9222 ± 25
10090	8377	10326	9186 ± 22
10091	8347	10296	9220 ± 22
10097	8337	10286	9179 ± 21
10098	8317	10266	9164 ± 21
10115	8297	10246	9191 ± 23
10337	8286	10235	9065 ± 25
10116	8276	10225	9086 ± 25
10338	8266	10215	9021 ± 25
10127	8251	10200	9097 ± 25
16081	8243	10192	9030 ± 21
16093	8223	10172	8967 ± 25
16100	8203	10152	8960 ± 20
16106	8183	10132	8894 ± 23
16110	8163	10112	8934 ± 20
16635	8148	10097	8835 ± 23
16068	8143	10092	8847 ± 23
16082	8143	10092	8850 ± 24
16595	8138	10087	8871 ± 27
16596	8131	10080	8841 ± 20
16290	8111	10060	8859 ± 21
16289	8091	10040	8907 ± 21
9769	8077	10026	8856 ± 22
16082	8061	10010	8935 ± 22
16216	8021	9970	8930 ± 23
16593	8011	9960	8921 ± 21
16594	8001	9950	8894 ± 24
16385	7981	9930	8890 ± 24

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